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THE CARTERS BRIDGE, VIRGINIA, EARTHQUAKE OF FEBRUARY 27, 1977

David K. Lasch

In order to describe the Carters Bridge earthquake it will be necessary to define a few terms. The *epicenter* of an earthquake is that point on the surface of the Earth which is directly above the focus of an earthquake. It is also important to realize that there are two scales used in describing the size and effects of an earthquake. One measure is referred to as the Richter *magnitude* scale and is named after the person who devised it, C. F. Richter. Another useful measure is the Modified Mercalli *intensity* scale which was proposed by G. Mercalli.

The Richter magnitude is a measure of the size of an earthquake. It is calculated from a formula once the distance from the seismometer site to the epicenter, the magnification of the system, and the amplitude and period of a specific phase have been determined. It is a quantitative measure. The Richter magnitude scale is nonlinear, and it is logarithmic with a base of 10. Therefore, a magnitude 2.4 earthquake is 10 times larger than a magnitude 1.4. There will be only one magnitude value per earthquake. Finally, the Richter scale is unbounded — it has no upper or lower limit.

The Modified Mercalli intensity scale is used to describe the physical effects of an earthquake. Its range extends from I, not felt, to XII, total destruction. An earthquake will generally exhibit a range of intensity values, that is, extending from "not felt" to some Roman numeral describing the effects in the area closest to the epicenter, referred to as the maximum intensity value, which is usually given to typify or classify a given earthquake (Table 1).

Finally, an *isoseismal map* or "felt area" map should be explained. An isoseismal map depicts that area on the surface of the Earth upon which the earthquake was either felt or some evidence of its occurrence, such as cracked plaster, broken windows, or damaged chimneys, was observed. The map is constructed by plotting intensity values, obtained from actual accounts by individuals as well as Earthquake Report questionnaires that were mailed to residents in the vicinity of the earthquake, and then contouring the values (Figures 1, 2).

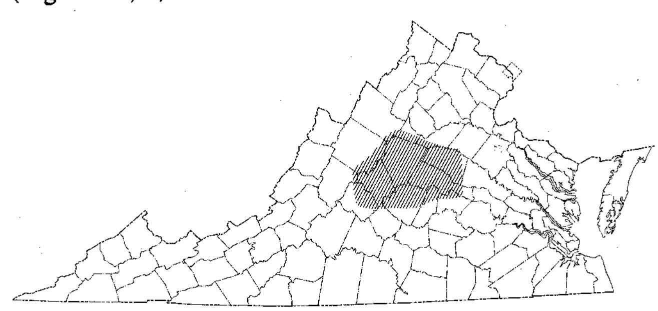

Figure 1. Index map showing area being discussed.

The area under consideration is wholly within the central Virginia seismic zone (Bollinger, 1973a). During the past 200 years there have been at least 31 reported earthquakes in the area (Bollinger, 1975a) (Figure 3). The earliest recorded earthquake occurred in Nelson County on March 16, 1775. The maximum intensities of the earthquakes ranged from III (felt quite noticeably indoors) to VI (felt by all). Magnitude determinations have been calculated only for the three earthquakes with instrumentally determined epicenters, that is, near Louisa, December 11, 1969, a magnitude of 3.5; near Columbia, November 7, 1974, a magnitude of 2.4; and near Carters Bridge, February 27, 1977, a magnitude of 2.4. The seismicity in the vicinity of Albemarle County is a subset of the central Virginia seismic zone which is only a part of the overall seismic regime of the State. Also, the seismic regime of the State is only a part of the regional seismicity of the eastern United States.

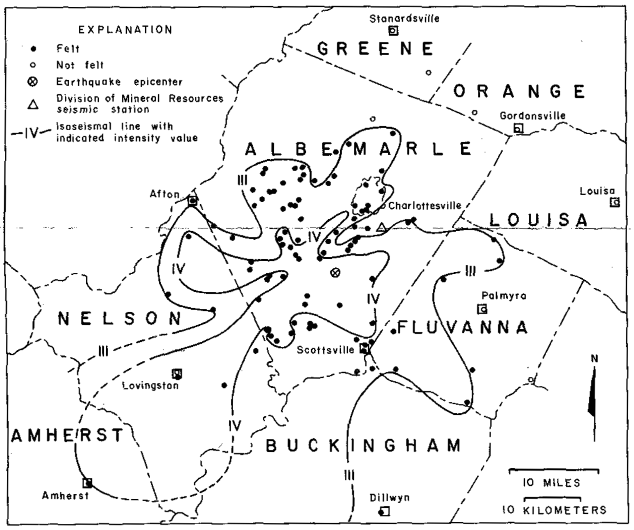

Figure 2. Isoseismal map, Carters Bridge, Virginia, earthquake, February 27, 1977.

A method has been developed to indicate the intensity and frequency of occurrence of earthquakes for a given region. The method, cumulative intensity mapping, has been applied to the 200-year earthquake data base for Virginia (Stewart, Ferguson, and Bollinger, 1975). Maps for various intensity levels were produced which combined the data from Modified Mercalli isoseismal maps for each earthquake that was felt within the State. The cumulative intensity maps show the historical earthquake frequency for any desired intensity level for the entire area under study.

Their study shows that the effects of an event of intensity VI have been experienced at least three times in the vicinity of Albemarle County, once during the first 100 years (1774-1873) of recorded data and twice during the remaining period (1874-present). If an intensity level of greater than or equal to V is chosen, it can be seen that the effects have been experienced in the area under discussion approximately five to eight times during the past 200 years.

An earthquake occurred at approximately 3:05 P.M. EST on Sunday, February 27, 1977, near Carters Bridge, south-central Albemarle County. The earthquake had a magnitude of 2.4 and a maximum intensity value of IV.

An intensity survey was conducted immediately after the Carters Bridge earthquake. More than 200 responses were used to construct the isoseismal map shown in Figure 2. The solid dots show that the earthquake was felt or some earthquake-related effect was observed at that particular location. Each response indicating that the earthquake was noticed was assigned a value from the Modified Mercalli intensity scale. The values were then contoured. The open dots show responses from locations where the earthquake was unnoticed. These points are useful in delimiting the areal extent of the isoseismal map.

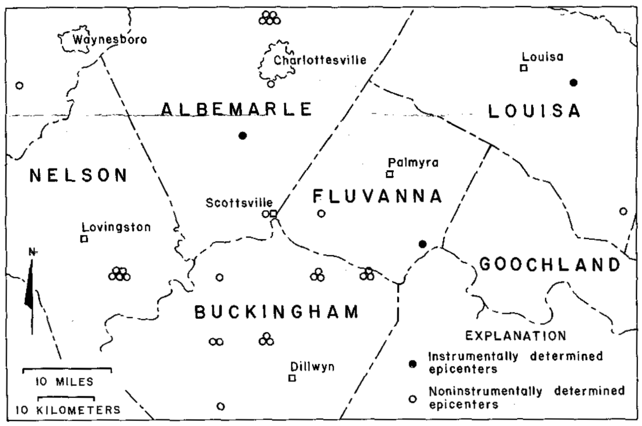

Figure 3. Earthquake epicenters in the vicinity of Albemarle County, Virginia, March 1775 through June 1977.

Usually the shape of the isoseismal map is the most important result of an intensity survey. Sometimes the map will exhibit trends that will delineate the regional structure of an area. Note that the isoseismal map is elongated in a northeasterly-southwesterly direction. This is consistent with the northeasterly-southwesterly Appalachian trend observed in most isoseismal maps of the southeastern states (Bollinger, 1973a). It should be noted that the shape of the isoseismal map will also be affected to some extent by the areal distribution of the questionnaire responses.

The more uniform the azimuthal distribution of responses the more certain it will be that the shape of the isoseismal map is reflecting an actual geologic setting.

The seismic history of Albemarle County and vicinity is shown in Figure 3. The groupings of two, three, and five epicenters are intended to indicate that this number of earthquakes occurred at the same latitude and longitude. The groupings are not meant to show an east-west trend, but merely to denote that more than one earthquake occurred at that particular location.

Of the 31 epicenters only three can be considered as accurately located. They are the most recent events—Louisa, 1969, Columbia, 1974, and Carters Bridge, 1977. They were located by using seismograms recorded at

Table 1. —Earthquakes occurring in the vicinity of Albemarle County, Virginia.

Year	*Date*	*General Location*	*Intensity/ Magnitude*
1775	March 16	Nelson County	V
1775	August 30	Nelson County	-
1791	January 13	Nelson County	IV
1856	March 21	Nelson County	III
1878	January 2	Louisa County	III
1885	October 9	Nelson County	V
1886	September 1	Charlottesville	-
1907	February 10	Scottsville	III
1907	February 11	Arvonia	VI
1910	May 8	Arvonia	V
1912	August 7	Arvonia	IV
1921	August 7	New Canton	VI
1927	June 10	Augusta County	V
1929	December 26	Charlottesville	VI
1931	October 5	New Canton	-
1932	January 4	Buckingham County	V
1933	July 23	New Canton	III
1936	April 9	Charlottesville	III
1937	February 2	Albemarle County	III-IV
1942	October 6	Buckingham County	III
1945	October 10	New Canton	-
1945	October 12	Dillwyn	-
1945	October 29	Dillwyn-New Canton	-
1946	May 24	Albemarle County	-
1948	January 4	Buckingham County	IV
1948	March 26	Charlottesville	-
1950	November 26	Buckingham County	V
1952	September 10	Charlottesville	IV
1969	December 11	Louisa	IV/3.5
1974	November 7	Columbia	2.4
1977	February 27	Carters Bridge	IV/2.4

the various seismic stations within the southeastern states and are shown on Figure 3 as solid dots, that is, instrumentally determined epicenters. The 28 open dots, noninstrumentally determined epicenters, were located using historical or archival data—diaries, journals, or newspapers. The epicenter locations are therefore rather approximate; they are accurate to within about ±62 miles (100 km) (Bollinger, 1975b). Unfortunately, the inaccuracy in the location of these epicenters precludes any definite correlations between the seismicity and the local geology. The inaccuracy in the epicenter locations, however, would not have such a deleterious effect on correlations with large-scale tectonic features.

Currently there are at least four distinct hypotheses which attempt to explain the occurrence of earthquakes in the southeastern United States. The spatial relationship between mafic intrustions and earthquake epicenters was first pointed out by Fox (1970). He proposed that local stress concentrations could possibly result from crustal warping but did not attempt to relate the stresses to the mafic intrusions. It has been suggested by Bollinger (1973b) that a possible mechanism for the earthquakes may be the concentration of stress by old Appalachian structures. A similar model, proposing that earthquakes occur on existing faults, was suggested by Sbar and Sykes (1973). Long (1976) has proposed the concept of "stress amplification," that is, anomalously rigid crustal units, which may or may not be mafic units, have a shape that permits amplification or concentration of regional stresses. Earthquakes could be triggered by a change in the stress field which could be related to differential uplift or plate movements.

There are inherent difficulties in applying geological data and historical seismic data. The geological data may be insufficient to indicate the existence, depth, or size of mafic units, faults, or other structures that may or may not be exposed at the Earth's surface. Also, the seismic history may be too short to allow a correlation between the epicenters and the associated geological features. Finally, as indicated earlier, the uncertainty of the location of the epicenters from historical or archival data is large relative to the areal extent of many geological features.

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GEOLOGICAL ABSTRACTS — VIRGINIA SECTION OF SOCIETY OF MINING ENGINEERS

Abstracts of seven papers presented at the Spring meeting on April 22, 1977 of the Virginia section of the Society of Mining Engineers of AIME (American Institute of Mining, Metallurgical, and Petroleum Engineers) in Charlottesville, Virginia follow.

REGIONAL GEOLOGY OF THE VIRGINIA PIEDMONT: A SUMMARY. James F. Conley, Virginia Division of Mineral Resources, Charlottesville, VA 22903.

Virginia contains two areas of exposed Grenville basement—the Sauratown Mountains anticlinorium and the Blue Ridge anticlinorium. Overlying the basement on the southeastern limb of the Blue Ridge anticlinorium is a sequence of rocks consisting (from oldest to youngest) of Lynchburg, Catoctin, Candler, and Chopawamsic formations. If this sequence is correct, the stratigraphic order in the James River synclinorium and even the existence of this synclinorium is questioned. Rocks in the Sherwill anticline are correlated with those in the Smith River allochthon. The Chopawamsic Formation is correlated with metavolcanic rocks to the southwest at Danville. Rocks of the Carolina slate belt are suggested to conformably overlie these metavolcanic rocks at Danville. Rocks of the Quantico and Arvonia synclines are tentatively correlated with each other and are thought to unconformably overlie the Chopawamsic Formation. The Quantico syncline is thought to be folded around the northwest limb and nose of the later Columbia syncline. With increasing metamorphic grade to the southeast, rocks of the Chopawamsic Formation grade into the Hatcher Complex.

COMPARISON OF MASSIVE SULFIDE MINERALOGY AT GOSSAN LEAD WITH THE COFER PROPERTY, MINERAL, LOUISA COUNTY, VIRGINIA. James R. Craig, J. William Miller, and Donald K. Henry, Department of Geological Sciences, Virginia Polytechnic Institue and State University, Blacksburg, VA 24061.

The Great Gossan Lead district and the Cofer prospect represent massive base-metal deposits with contrasting mineralogies. The Great Gossan Lead is a northeastward-trending, discontinuous mineralized belt, roughly parallel to metamorphic foliation, approximately 20 miles in length in Carroll and Grayson counties of southwestern Virginia. The pod-like ore lenses are generally massive, fine-grained hexagonal pyrrhotite, which exhibits textural (injection into and interleaving with silicate gangue) and structural (kink-banding) evidence of having been subject to metamorphism with the enclosing host rocks. Minor amounts of chalcopyrite, sphalerite, galena, and pyrite and traces of bismuth, arsenopyrite, cubanite, mackinawite, and stannite occur as irregular disseminations in the pyrrhotite.

The Cofer prospect contains a series of roughly parallel discontinuous lenses concordant with the enclosing metamorphic rocks near Mineral, Louisa County. The ores vary from zones of massive granular pyrite to zones of disseminated sphalerite; apparent original compositional banding is visible in many ore zones. Pyritic zones contain significant quantities of sphalerite and chalcopyrite, but only minor amounts of galena and arsenopyrite. Sphalerite-rich zones contain significant quantities of pyrite and galena, but only minor amounts of chalcopyrite. Trace amounts of electrum, tetrahedrite, mackinawite, pyrrhotite, Cu-Sb-Pb sulfosalts, and bornite are dispersed in the ores. Supergene development of covellite and chalcocite are present locally in the upper parts of the ore zones.

SELECTED EXPLORATION CASE HISTORIES IN THE VIRGINIA PIEDMONT. Donald W. Foss, North American Exploration, Inc., Charlottesville, VA 22901.

This paper presents a discussion of the regional geologic setting and history of exploration in a portion of the Virginia Piedmont. The area of study is located in Buckingham County, approximately 50 miles south of Charlottesville. Geochemical exploration methods and results are summarized, and optimum sampling parameters for the area are described. Selected soil profile data from three different areas are included. Geophysical data are presented for two anomalies within the study area. The geology of one of the anomalies is described in detail. Tonnage and grade, based upon an extensive drilling program, are presented.

STREAM SEDIMENT GEOCHEMISTRY IN FLUVANNA COUNTY AND THE DILLWYN REFERENCE AREA, CENTRAL PIEDMONT, VIRGINIA. Richard S. Good and Oliver M. Fordham, Jr., Virginia Division of Mineral Resources, Charlottesville, VA 22903.

A pilot study was made on -80 + 230 and -230 mesh fractions of 445 stream-sediment samples by hot 1:1 HCl and 3:2 HNO_3-$HClO_4$ acids using AAS for Zn, Cu, Pb, Ag, Fe, Mn, Cr, Ni, Co, Li, and Sr. Results are: (1) areas of known mineralization in the Arvonia syncline were indicated, areas of old gold mines in the Columbia syncline showed up rather poorly except by multi-element analysis, and several completely new base metal anomalies were discovered and are being investigated further; (2) the reference area showed that both methods of acid attack delineated strong anomalies more than 2 miles downstream or missed mineralization completely, depending on topography and drainage; (3) in the reference area HCl was about the same as HNO_3-$HClO_4$ for zinc, much better for lead, much lower but clearly anomalous for copper, and about the same for silver; (4) barite and pyrite could be quantitatively identified in the reference area; (5) both Fe and Mn were lower than normal in the reference area; (6) in background areas metal averages were 2 to 4 times as high for the clay-silt (-230 mesh) as the fine sand (-80 + 230 mesh) fractions; (7) metal anomalies in general were independent of magnetite content of sediment and most (>85 percent) of trace metals were in iron-oxide coatings, not magnetite; (8) combined routine binocular microscope and x-ray examination can be rapidly used for semiquantitative data on mica, chlorite, microcline, plagioclase, amphibole, epidote, and relative amounts of iron-oxides, which taken together correlate surprisingly well with bedrock type; (9) intermetal correlations were high for all elements analysed (0.5-0.8) except Sr; and (10) statistical computer treatment of multielement data accentuated anomalous areas and factor analysis delineated underlying geology of areas.

A CASE HISTORY IN MASSIVE SULPHIDE EXPLORATION IN THE VIRGINIA PIEDMONT FROM AIRBORNE GEOPHYSICS THROUGH DRILLING. Robert W. Hodder, University of Western Ontario, London, Ontario, and Richard F. Kazda, Callahan Mining Corporation, Charlottesville, VA 22901.

Airborne surveys near Mineral, Louisa County, Virginia, detected the M-31 anomaly as a short 6-channel conductor by Input Mark V, and as a grade 2 and 3 conductor by Dighem with coincident magnetic expression of 110 gammas above background. It was readily confirmed by ground EM surveys, has a positive gravity anomaly of 0.5 to 1.1 milligals, and soil with a total base-metal content of 2 to 40 times background. Five holes along 1,500 feet of strike length intersect gently dipping biotite-sericite schist enveloping 180 feet of biotite-amphibolite schist with 20 percent pyrrhotite and pyrite. Greatest base metal content is a disappointing 0.09 percent Cu over 21.5 feet.

M-31 is much more conductive than nearby larger massive base-metal sulphide bodies near Mineral, apparently because sulphide occurs in continuous stringers rather than the more common coarse grains isolated in silicate gangue. Pyrrhotite and magnetite explain the magnetic expression but specific gravities of 3.2 and 2.68 for mineralized interval and wall rocks do not account for the gravity anomaly. The geochemical anomaly is the contrast between thin residual soil over the sulphide-bearing interval with the same content as fresh rock and barren soil above barren rock.

The strata-bound nature, thin lithologic units, minor chemical sediment, and planar contacts suggest M-31 is a minor syngenetic concentration of iron sulphide at the top of a basaltic tuff deposited between rapid accumulations of an epiclastic rock. There appears not to have been local basins or time for precipitation of metalliferous chemical sediment between influxes of clastic debris. However, this interpretation could not be inferred prior to drilling in an area of sparse outcrop.

BIOGEOCHEMICAL EXPLORATION IN LOUISA COUNTY. Steven W. Leavitt and Horace G. Goodell, University of Virginia, Charlottesville, VA 22903.

Current geochemical exploration in the Piedmont province has been directed toward the use of soils and sediments as primary indications of mineralization. In order to test the effectiveness of biogeochemical methods vegetation and soils at 17 sites along two traverses across a mineralized zone north of Mineral, Virginia, were sampled and analyzed for Ag, Cd, Cu, Pb, and Zn. The sites were selected over the host rocks for the massive-sulfide mineralization, as well as over country rock in which sulfide deposits would not be expected to occur. Analyses were done by atomic adsorption using standard digestion and analytical techniques. Plant concentration of a metal expressed on a dry-weight basis gives more and higher correlations with soil metal concentrations than does the ashed-weight concentration. Mature leaves and twigs of the current year's growth of the oak group appear to be the best plants and plant organs for sampling. The plant concentrations correlate well with either the A or the B soil horizon. Zinc and cadmium concentrations in plants were most frequently correlated with any of the soil metals, but lead in plants was poorly correlated to soil metals; copper and silver are intermediate. Soils developed on the sulfides showed up to 25 fold increase in metal content. Although plants reflected the elevated metal concentrations of these soils the relative metal increases were substantially lower. Nevertheless plants are reliable indicators of mineralization.

STREAM SEDIMENT AND SOILS IN REGIONAL EXPLORATION GEOCHEMISTRY, NORTHERN VIRGINIA. Dash A. Sayala and Frederic R. Siegel, George Washington University, Washington, DC 20006.

A regional study of 7,200 sq km of northern Virginia was made comparing stream sediment, soils, and stream water in the Piedmont, Blue Ridge, and Valley and Ridge provinces. Four hundred and forty samples were analysed by atomic absorption spectrophotometry. The -200 mesh fraction was used for stream sediments and the -60 mesh for soil samples from a depth of 25 cm. A total fusion attack by lithium metaborate was used in sample preparation of soils and sediments. Elements analysed were Au, Mo, Pb, Zn, Fe, Mn, Ni, Cr, and Co.

Anomalous (mean + 2 standard deviations) areas found were: Mo in water in the Federicksburg area; Cu and Au anomalies in the gold pyrite belt near Mineral; Ag, Pb, and Zn in the Blue Ridge and Valley and Ridge; and Ni-Cr-Co associated with ultramafic rocks.

NEW AND REVISED PUBLICATIONS

(State sales tax is applicable only to Virginia addresses)

DIRECTORY OF THE MINERAL INDUSTRY IN VIRGINIA — 1977, by D. C. Le Van; 52 p. Price: \$0.50 plus \$0.02 State sales tax, total \$0.52.

Report of Investigations 3. GEOLOGY OF LURAY CAVERNS, VIRGINIA, by John T. Hack and Leslie H. Durloo, Jr.; 43 p., 1 map, 14 figs., 1962, figures revised 1977. Price: \$1.75 plus \$0.07 State sales tax, total \$1.82.

NEW MINERAL INDUSTRY REPORT

A recently released preprint from the 1974 U. S. Bureau of Mines Minerals Yearbook, "The Mineral Industry of Virginia," by C. E. Vannoy is available free from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903. This 14-page detailed report on mineral production for 1974 includes 1 figure and 13 tables. A brief advance summary of this information was published in *Virginia Minerals,* vol. 22, February 1976, p. 1.

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PUBLICATION ON ATLANTIC OFFSHORE PETROLEUM POTENTIAL

A publication released by the U. S. Geological Survey in mid-July 1977 concerns the COST No. B-2 well, which is the first deep stratigraphic test to be drilled on the United States Atlantic Outer Continental Shelf (AOCS) area. The well was drilled by Ocean Production Company acting as operator for a group of 31 petroleum companies. Water depth at the site is 298 feet, and drilling continued to a depth of 15,953 feet below sea level. The report, U. S. Geological Survey Circular 750, "Geological Studies on the COST No. B-2 well, U. S. Mid-Atlantic Outer Continental Shelf Area," by P. A. Schoole, editor, is available free from the Branch of Distribution, U. S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202. The conclusions as quoted from page 68 of this circular follow:

"1. The COST No. B-2 well penetrated nearly 16,000 feet of sediment in the Baltimore Canyon trough of the AOCS. The age of the sediments (determined through the examination of Foraminifera, calcareous nannofossils, and palynomorphs) is Cenozoic down to about 5,000 feet. From 5,000 to 8,100 feet, the sediments are Late Cretaceous in age, and from 8,100 feet to the base of the well, they are Early Cretaceous. Although no positive indications of Jurassic sediments were found in this well, a Jurassic age cannot be ruled out for the basal 1,000 to 2,000 feet of section.

"2. Early Cretaceous depositional environments in the B-2 area were apparently primarily nonmarine; occasional shallow marine incursions took place. The Late Cretaceous environments were generally shallow marine, with the exception of a nonmarine interval during the Coniacian and Santonian. During the Eocene, water depths were similar to those found on present continental slopes; later Tertiary sediments were deposited in outer- to inner-shelf environments.

"3. The dominant lithologies found were sandstone and shale and minor limestone, coal, and lignite. Sand-shale ratios vary with depth but generally are 25 to 65 percent.

"4. Porosites and permeabilities in the sandstone and shale section decrease rapidly as depth increases, so that below 12,000 feet, most sandstones have less than 15 percent porosity and 1 millidarcy permeability.

"5. Petrographic analysis indicates that most of the sandstone is feldspathic. Much of the porosity loss seen at depth is due to breakdown of feldspar and the generation of authigenic clay and silica cement. Calcite cement is also very important, especially in zones having primary calcareous components.

"6. The present geothermal gradient in the COST No. B-2 well is 1.3 °F./100 feet.

"7. Organic geochemistry and color alteration of visible organic matter, in conjunction with vitrinite reflectance, indicate either immaturity or low thermal maturity for most of the section down to at least 12,000 feet. Furthermore, although many units have very high organic carbon contents (as much as 12 percent), most of the sediments in the most thermally mature zones have terrestrially derived organic matter.

"8. The combination of all the above factors indicates a relatively low potential for liquid-hydrocarbon generation and a relatively high potential for natural-gas generation. Deeper parts of the section (below 16,000 feet) or other parts of the Baltimore Canyon trough may have the potential to generate oil or gas, depending on the amount and character of their contained organic matter."

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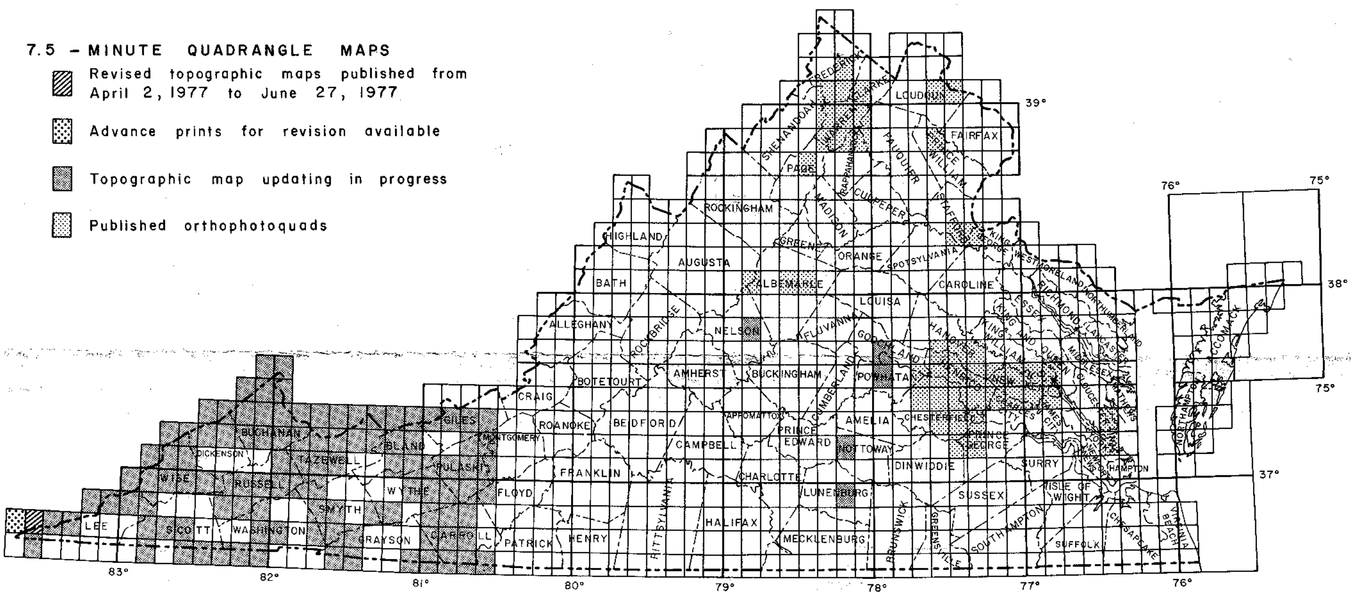

Revised 7.5-minute quadrangle maps published from April 2 to June 27, 1977:

Revised Maps	Advance Prints for Revision
Varilla	Middlesboro North

ADVANCE PRINTS

Advance prints are available at $1.25 each from the Eastern Mapping Center, Topographic Division, U. S. Geological Survey, Reston, Virginia 22092.

PUBLISHED TOPOGRAPHIC MAPS

Total State coverage completed; index is available free. Updated photorevised maps, on which recent cultural changes are indicated, are now available for certain areas of industrial, residential, or commercial growth. Published topographic maps for all of Virginia or available orthophotoquads may be purchased for $1.25 each (plus 4 percent State sales tax for Virginia addresses) from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903. A listing of available orthophotoquads is free upon request from the Division.